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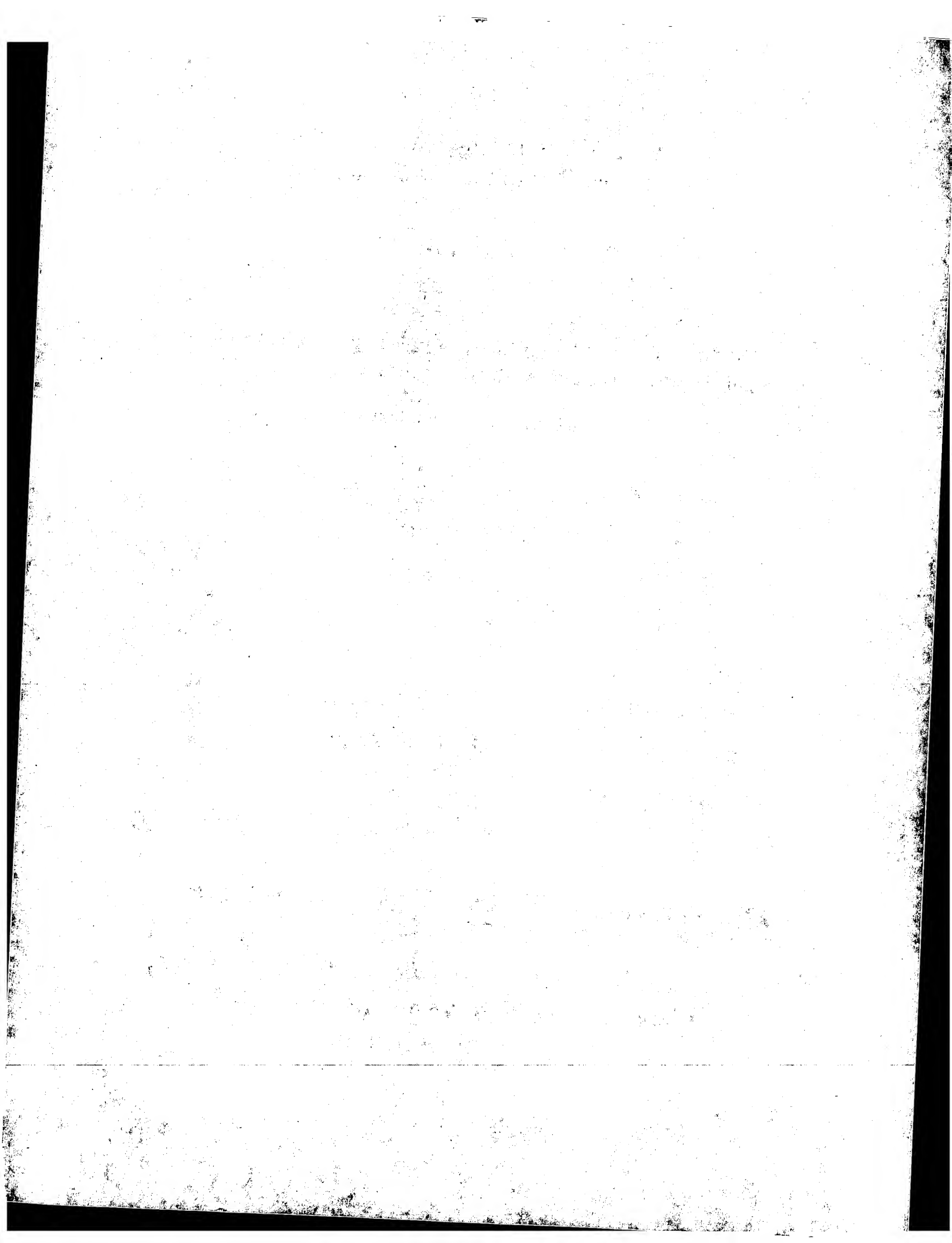
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(21) International Application Number: PCT/US96/10162 (22) International Filing Date: 12 June 1996 (12.06.96) (30) Priority Data: 08/490,969 15 June 1995 (15.06.95) US (71) Applicant: UNIVERSITY OF AKRON, THE [US/US]; 302 East Buchtel Avenue, Akron, OH 44325 (US). (72) Inventors: KENNEDY, Joseph, P.; 510 St. Andrew Street, Akron, OH 44303 (US). ZASCHKE, Bernd; Warthaer Street 2A, D-01157 Dresden (DE). (74) Agents: WEBER, Ray, L. et al.; Renner, Kenner, Greive, Bobak, Taylor & Weber, 1610 First National Tower, Akron, OH 44308-1456 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
(54) Title: CATIONIC MULTIBLOCK THERMOPLASTIC ELASTOMERS (57) Abstract The synthesis and characterization of a series of novel (AB) _n multiblock copolymers, typically thermoplastic elastomers, containing polyisobutylene as the soft phase and polyamides as the hard phase are described. First, carboxyl ditelechelic polyisobutylene prepolymers and isocyanate ditelechelic polyisobutylene prepolymers were synthesized, both of which were subsequently reacted under solution polycondensation conditions with dicarboxylic acids and diisocyanates. The melting points of the polyamide hard phases were in the 223-284 °C range. The decomposition temperatures (296-337 °C) in air and nitrogen of these thermoplastic elastomers were quite similar; in contrast, these properties of polytetrahydrofuran-based thermoplastic elastomers are noticeably lower in air. Melt processing of these novel polyisobutylene-based thermoplastic elastomers is possible.		

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Cationic Multiblock Thermoplastic Elastomers

Technical Field

The invention described herein pertains generally to multiblock thermoplastic elastomers prepared by cationic polymerization.

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Background of the Invention

A body of literature exists on the synthesis and properties of polyisobutylene (PIB) based linear and three arm star thermoplastic elastomers (TPE) containing a variety of hydrocarbon hard phases with T_g 's or in one case T_m in the 100 - 240°C range. However, there is a lack of information on related (AB)_n-type multiblocks comprising rubbery PIB blocks connected to glassy or crystalline segments. Only PIB multiblocks with polyurethane and polybutyleneterephthalate hard phases have been described. There does not appear to be any discussion regarding the synthesis of (AB)_n type multiblock thermoplastic elastomers with polyisobutylene (PIB) soft segments connected to polyamide (PA) hard segments. Polyamides promise to yield desirably high melting crystalline blocks (mp = 220 - 280°C) coupled with improved thermal and chemical environmental resistance, melt processability, at reasonably low cost.

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Summary of the Invention

In accordance with the present invention, there is provided a series of novel cationic thermoplastic elastomers and processes by which cationic multiblock thermoplastic elastomers can be synthesized.

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It is an object of this invention to provide the synthesis of (AB)_n type multiblock thermoplastic elastomers with polyisobutylene soft segments connected to polyamide hard segments.

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These and other objects of this invention will be evident when viewed in light of the drawings, detailed description, and appended claims.

Brief Description of the Drawings

The invention may take physical form in certain parts and arrangements of parts, a preferred embodiment of which will be described in detail in the

specification and illustrated in the accompanying drawings which form a part hereof, and wherein:

Fig. 1 shows gel permeation curves of HO-PIB₁₀₀₀-OH, HOOC-PIB₁₀₀₀-COOH and PIB₁₀₀₀-PA2.

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Detailed Description of the Invention

Referring now to the drawings wherein the showings are for purposes of illustrating the preferred embodiment of the invention only and not for purposes of limiting the same, the Figures show the successful synthesis of multiblock thermoplastic elastomers prepared by cationic polymerization.

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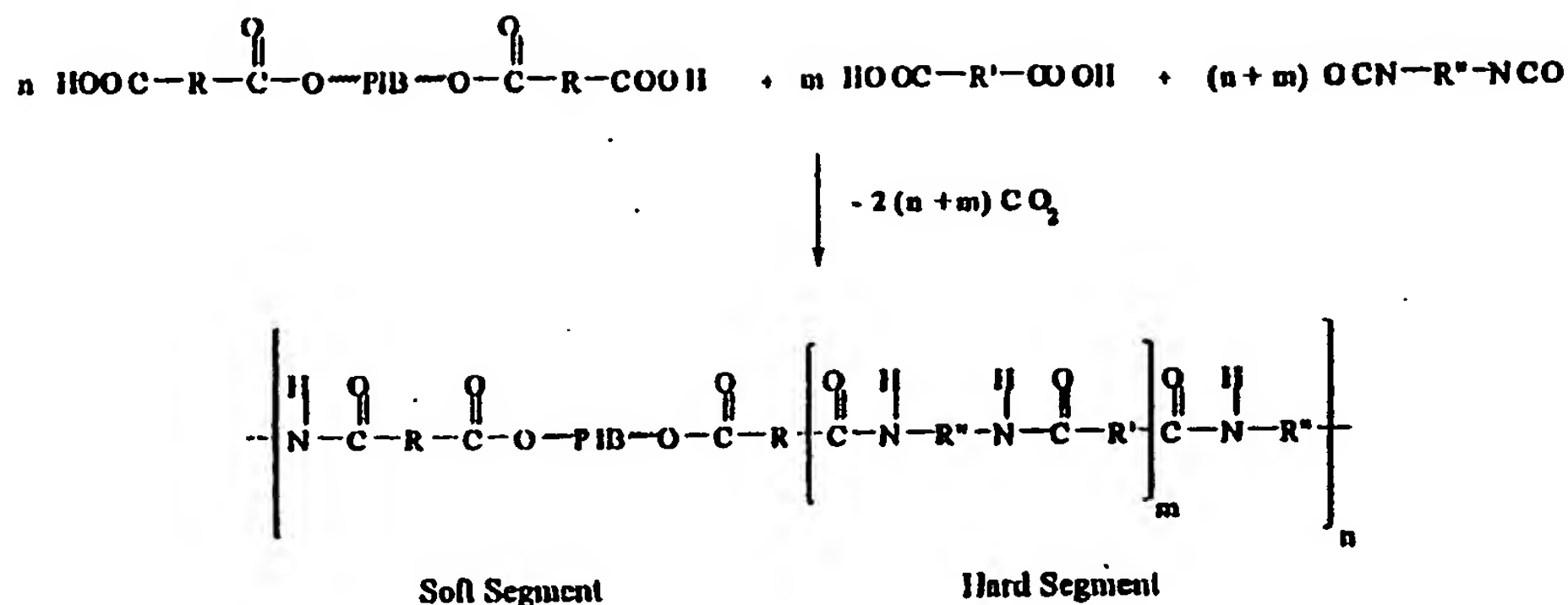
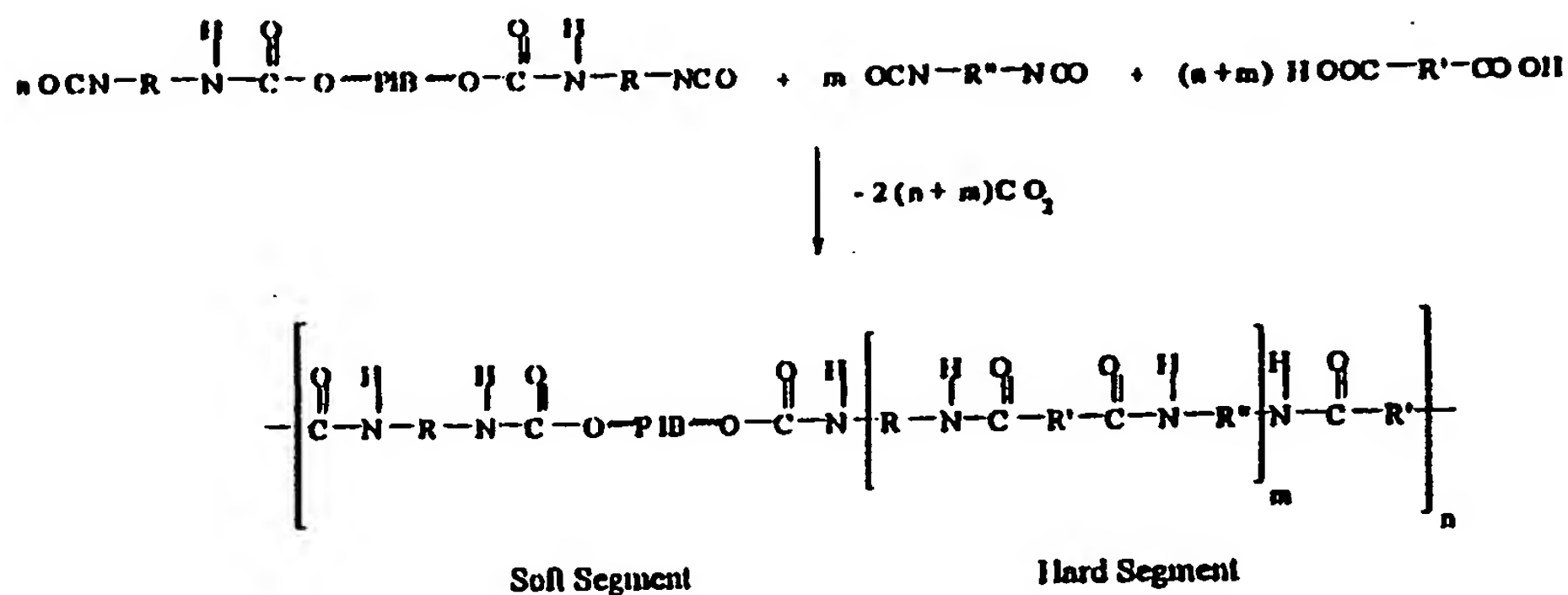
The best mode for carrying out the invention will now be described for the purposes of illustrating the best mode known to the applicant at the time. The examples are illustrative only and not meant to limit the invention, as measured by the scope and spirit of the claims.

Synthetic Strategy

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Several alternatives for the synthesis of (PIB-PA)_n multiblocks were tried. In view of the immiscibility of nonpolar polyisobutylene and polar polyamide ditelechelic prepolymers in the melt, the solution polycondensation of HOOC- or OCN- terminated ditelechelic polyisobutylenes with various diisocyanates and dicarboxylic acids were found to be effective. Equations #1 and #2 diagram the pathways for the synthesis of (PIB-PA) multiblocks.

20

Equation #1**Equation #2**

Experiments showed that all the envisioned polar and nonpolar reactants could be dissolved in mixed solvent systems such as tetramethylenesulfone (TMS)/xylene, γ -butyrolactone/xylene and TMS/*o*-chlorobenzene at elevated temperature. The boiling points of these solvent systems were above 150°C, a desirable temperature for polycondensation reactions. Various catalysts were determined to be effective in accelerating the polycondensation reaction and included 1,3-dimethyl-3-phospholene-1-oxide, 1,3-dimethyl-2-phospholene-1-oxide, CH₃ONa, CH₃OLi, PhOLi, and lithium-lactamates. Much of the experimental work presented

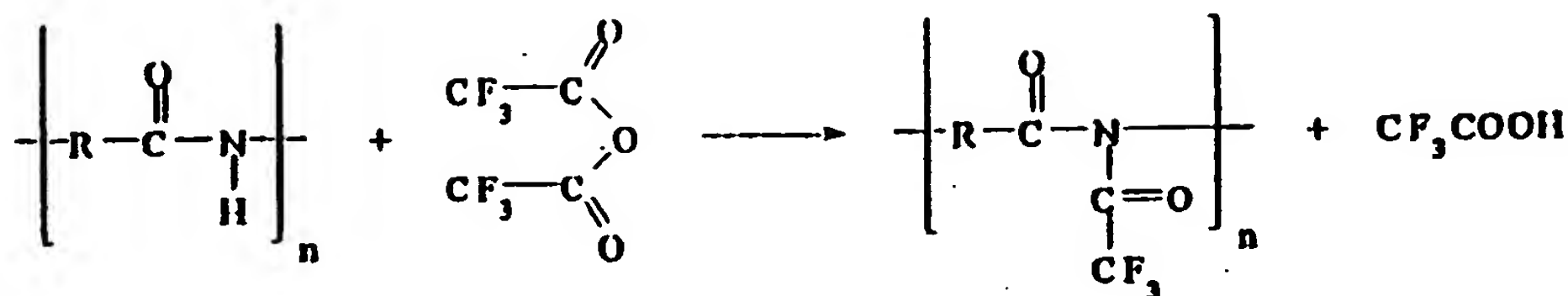
in this application focuses on CH_3ONa because of its commercial availability and low cost, however, the application is not limited to this catalyst.

Experimental

Dicarboxylic acids (Aldrich Chemical Co.) were dried in vacuum before use. Diisocyanates (Aldrich Chemical Co. or Pfaltz & Bauer) were used without further purification. The OCN- functionality was checked by back titration with di-*n*-butylamine followed by HCl. A non-limiting specific list of reagents would include the following dicarboxylic acids and diisocyanates: adipic acid, azelaic acid, 1,4-cyclohexane-dicarboxylic acid (cis and trans), toluene diisocyanate (TDI), p,p-diphenylmethanediisocyanate (MDI), 1,6-diisocyanatohexane (HDI), 1,3-bis-(isocyanatomethyl)-benzene (XDI) and 1,3-bis-(isocyanatomethyl)-cyclohexane (HXDI) (cis and trans). In general, it is expected that all dicarboxylic acids as shown by general formula $\text{HOOC-R}_{16}\text{-COOH}$ would be effective in the reaction, wherein R_{16} is C_{2-20} aliphatic, cycloaliphatic, aromatic, aralkyl or alkaryl moiety, said moiety optionally containing substituents such as halogens. Similarly, it is expected that all diisocyanates as shown by the general formula $\text{OCN-R}_{17}\text{-NCO}$ would be effective in the reaction, wherein R_{17} is defined similarly to R_{16} .

Characterization

Molecular weights and molecular weight distribution were determined by using a Waters high pressure GPC instrument equipped with refractive index (RI), ultraviolet (UV) and a three angle light scattering detector (Minidawn by Wyatt Technology Corp.). Five Ultrastyrigel columns (100, 500, 1000, 10000, 100000 Å) and THF solutions (injection 100 μL) were used. The calibration curve was obtained with polyisobutylene standards. Because of the strong hydrogen bonds between the amide groups, polyamides are insoluble in THF. However, after N-trifluoroacetylation of the amide groups as shown in Equation #3,



both homopolymers and block copolymers became soluble in THF, rendering GPC and light scattering characterization possible. Thus all of the GPC determinations were carried out by the use of trifluoroacetylated polymer.

¹H-NMR

- 5 ¹H-NMR spectra were obtained by the use of a Varian Gemini-200 instrument (200 MHz). Sample concentrations were about 20 mg/mL in CDCl₃. Typically, 128 transients were accumulated with 60° pulses (18 μs), 2.7 seconds acquisition time, and 4 seconds delay.

¹³C-NMR

- 10 Sample concentration 300 mg/mL in CDCl₃, accumulation 12 h.

Differential Scanning Calorimetry (DSC)

A model DSC 2910 Du Pont Instruments, was used with a heating rate of 10°C/min. All the DSC data reflect 2nd heating cycle.

Thermal Gravimetric Analysis (TGA)

- 15 A Du Pont instruments, 951 Thermogravimetric Analyzer was employed using a heating rate 10°C/min, gas flow 60 mL/min, N₂ or air. Decomposition temperature equaled 5 % weight loss.

Mechanical Properties

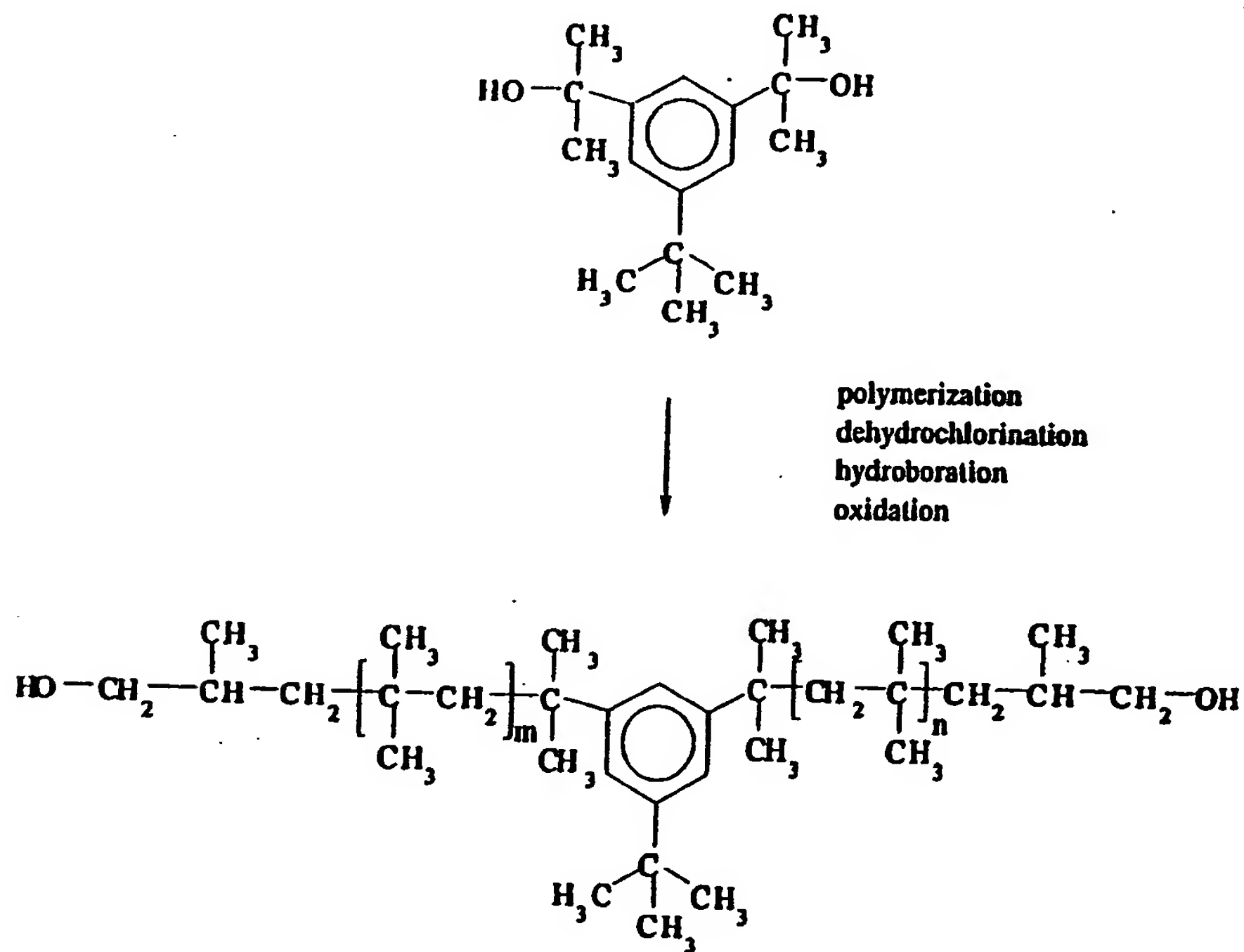
- 20 Compression molded sheets were obtained in a Carver press (~20°C above the melting point of the polyamide moieties, at ~50 kN). Mechanical properties were determined on dumbbells punched from the above sheets by the use of a Monsanto Tensiometer 10, Rate: 50.8 and 508 mm/min.

Preparation of Soft Segment Prepolymers**(a) HO-PTHF-OH**

Hydroxyl ditelechelic PTHF (Aldrich Chemical Co.) was used without further purification. Product characteristics are shown in Table 1. The subscripts
5 in the symbols in the column headings indicate the number average molecular weight (M_n) of the polyisobutylene or polytetrahydrofuran segments.

(b) HO-PIB-OH

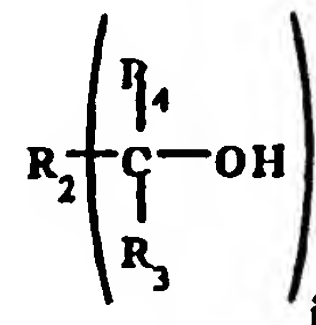
Hydroxyl ditelechelic polyisobutylenes were prepared by a well established procedure shown below in Equation #4.



- 10 The aim was to prepare prepolymers of $M_n \approx 1000$ and ≈ 2000 g/mol, narrow molecular weight distributions, and capped by exactly two terminal HO-groups (F_N = number average terminal functionality = 2.0 ± 0.05). According to ^{13}C -NMR

spectroscopy shown in Table I, this degree of functionality was achieved. The T_g 's of the rather low molecular weight products, -49 and -61°C , are higher than that of conventional high molecular weight polyisobutylene (-73°C), most likely because of the relative large initiator fragment (216 g/mol) in the statistical middle of the short polyisobutylene chain. Molecular characterization data of the HO-PIB-OH product are summarized in Table I.

While only one initiator is shown in the above equation, it is known that other initiators are effective in the polymerization of polyisobutylene with at least two functional groups attached thereto. In fact, initiators of the following generic formula:

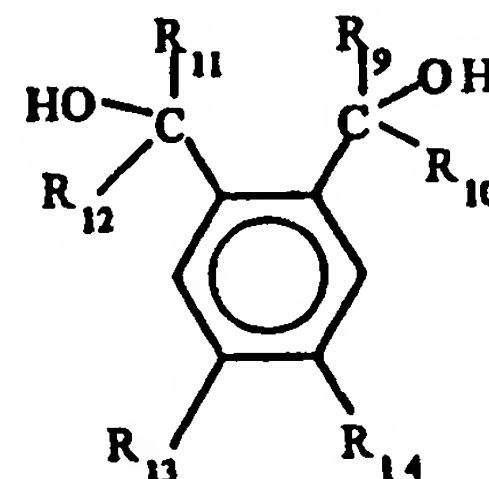
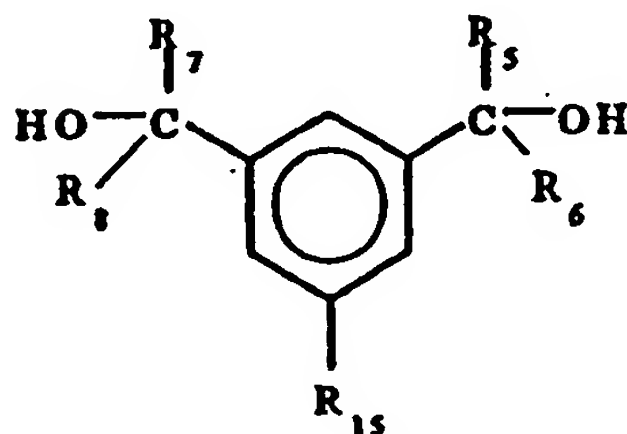


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would also be effective in the polymerization of isobutylene. In the above Markush formula, exemplary non-limiting definitions would include:

$R_2 =$ C_{1-24} alkyls, halogenated alkyls, aryl having from 1 to 4 phenyl rings, either noncondensed such as phenyl, biphenyl or terphenyl or condensed rings such as naphthalene, anthracene, phenanthrene or pyrene (in a preferred embodiment, R_2 is aryl or a substituted aryl)

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wherein the substituents $R_3 - R_{12}$ are independently hydrogen or alkyl groups having from C_{1-5} and R_{13-15} are independently hydrogen or alkyl groups having from C_{1-5} carbons or cycloalkyl groups having from C_{4-6} ;

5 $R_3 =$ hydrogen, methyl or phenyl;

$R_4 =$ can independently be the same or different from R_3 ; and

$i =$ an integer which is at least 2, and in a preferred embodiment, $i = 2$.

Table 1

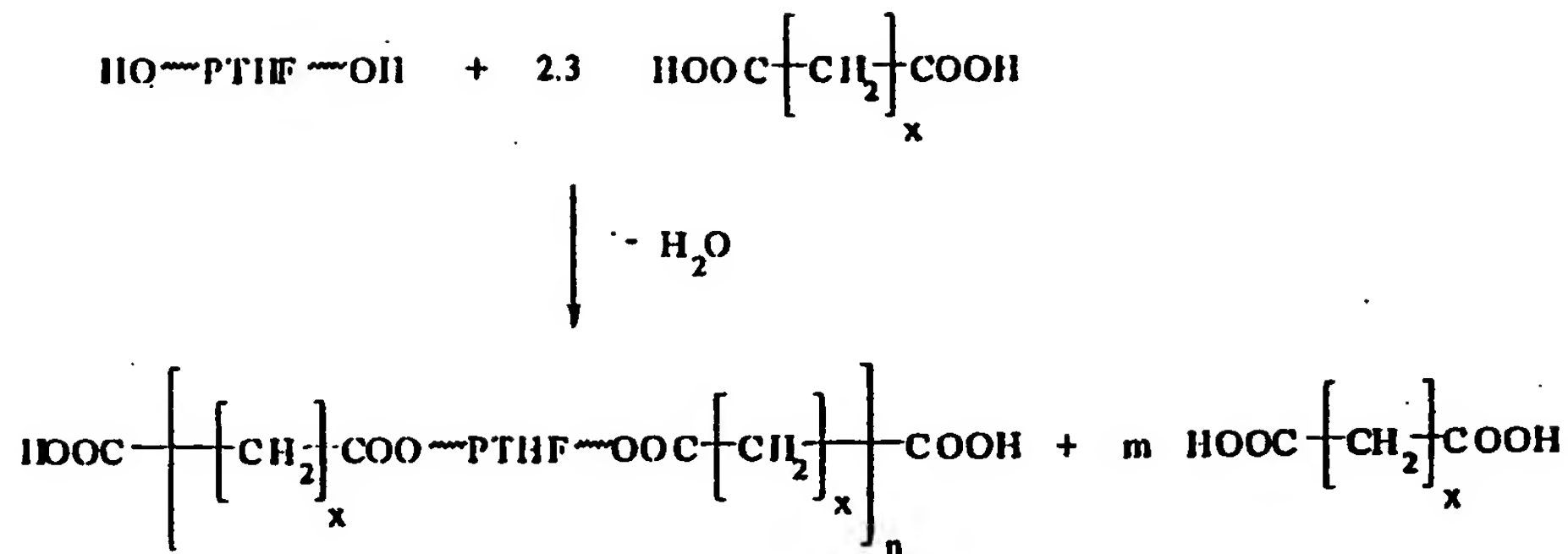
Characteristics of Hydroxyl Ditelechelic Prepolymers

Property	HO-PTHF ₁₀₀₀ -OH	OH-PIB ₁₀₀₀ -OH	OH-PIB ₁₉₅₀ -OH
M_n [g/mol] (¹³ C-NMR)	1000	975	1950
M_n [g/mol] (¹ H-NMR)	930	1060	2140
HO-F _N (¹ H-NMR & ¹³ C-NMR)		1.97	1.98
M_w/M_n (GPC)	1.535	1.057	1.036
T_g or T_m (°C)	$T_m: 23$	$T_g: -49$	$T_g: -61$
Decomposition temp (°C) in N ₂	274	358	382

25 (c) *HOOOC-PTIHF-COOH*

The following reaction (equation #5) was employed to synthesize this carboxylic acid terminated polytetrahydrofuran reactant.

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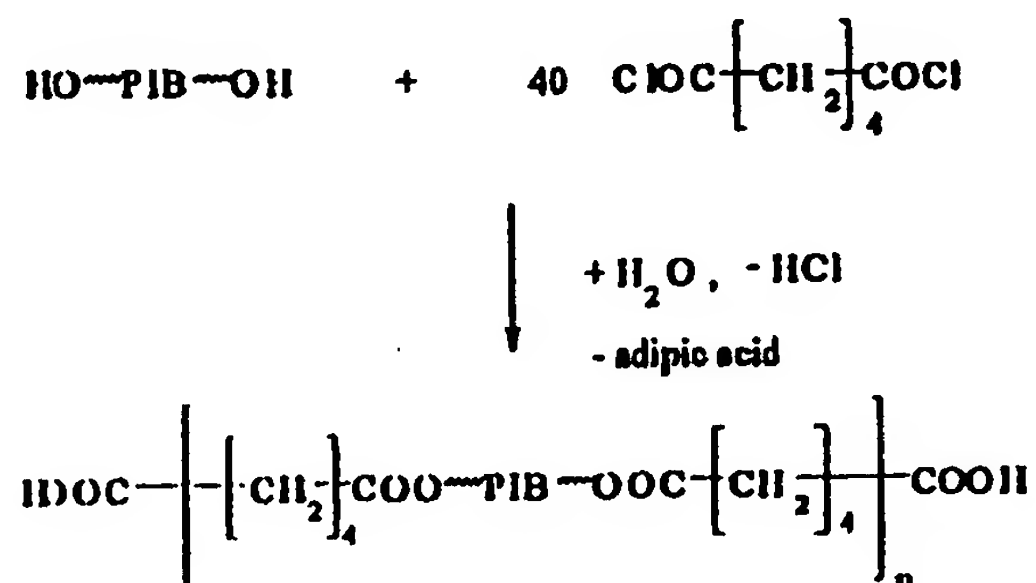
The advantage of this route is that the product can be used in subsequent polycondensations without prior purification since the unreacted adipic and azelaic acid (wherein x is 4 and 7 respectively) is consumed during polyamide formation.

¹H and ¹³C NMR analyses showed that the terminal hydroxyl groups were quantitatively converted. Table 2 shows the data collected in summary form.

(d) HOOC-PIB-COOH

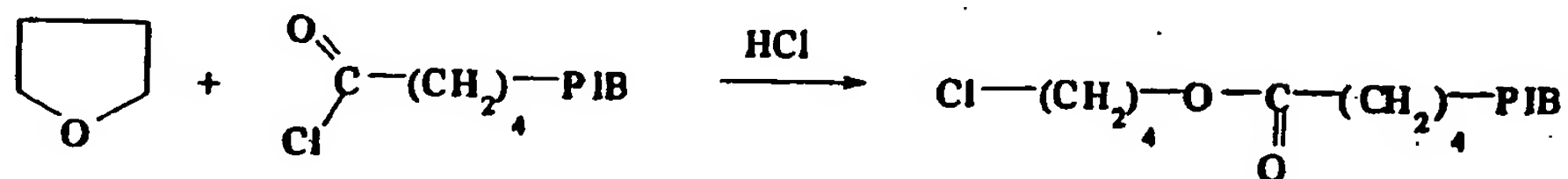
Efforts to adapt the route used for the synthesis of HOOC-PTHF-COOH (see above) for the preparation of HOOC-PIB-COOH were relatively unsuccessful because of excessive foaming, and even after three (3) days of refluxing using a Dean-Stark apparatus, only 56% of the hydroxyl groups had reacted. In a preferred embodiment, a large excess (40 x) of adipoyl chloride was used to suppress chain extension according to the following reaction scheme (equation #6).

15



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THF solvent was determined to consume approximately 2-5% of the polyisobutylene end groups, probably due to the following side reaction (equation #7).



By substituting benzene for THF this side-reaction was avoided and useful products were obtained. After removing the excess adipic acid, water, and pyridine, ¹H-NMR, ¹³C-NMR and GPC characterizations indicated satisfactory end-functionalization and the formation of only a small amount (8 - 10%) of chain extended product. Table 2 summarizes characterization data.

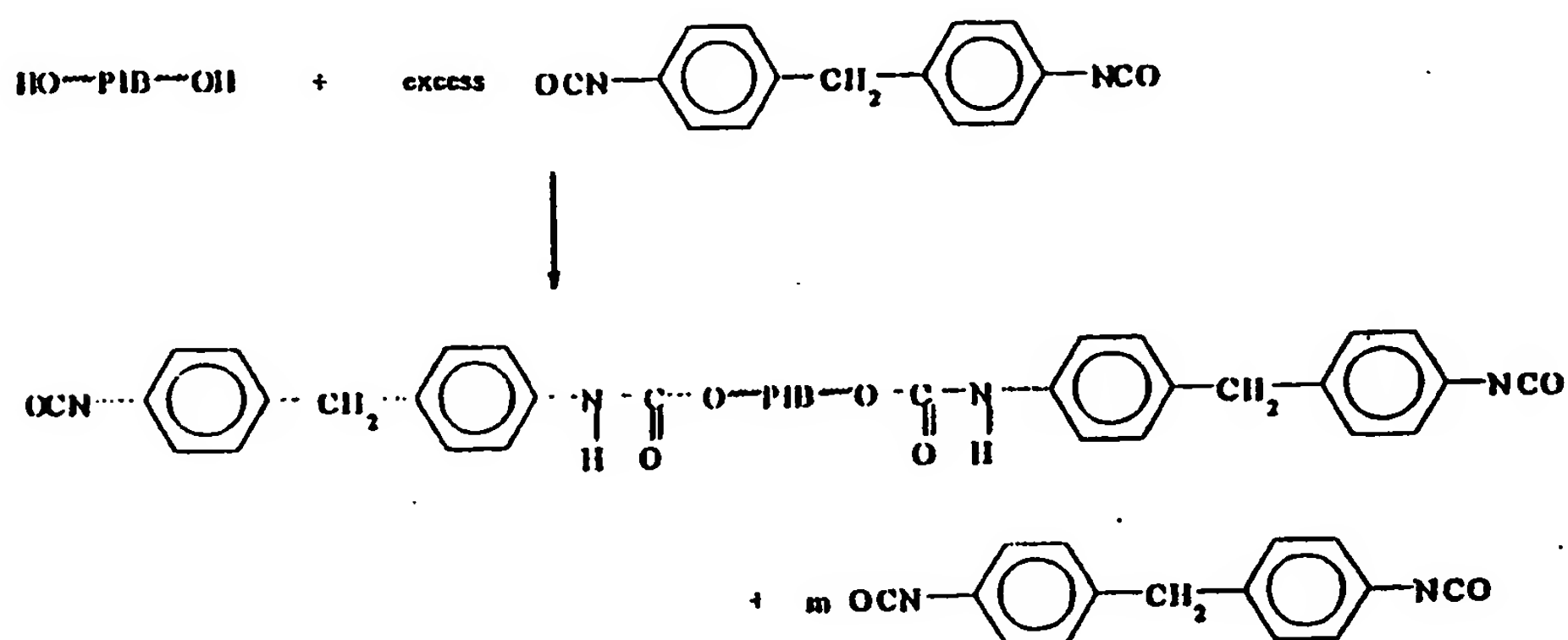
Table 2

Molecular weight, Molecular weight distribution and
Composition of carboxyl ditelechelic prepolymers

Prepolymer	Prep. by	M _n (¹³ C-NMR ^a) (g/mol)	M _w /M _n (GPC)	Product comp. GPC traces (%)	HOOC-P _n
HOOC-PIBF ₁₀₀₀ -COOH	Eq. #5	N.A.	1.78	broad trace	~2.0 ^b
HOOC-PIB ₂₀₀₀ -COOH	Eq. #6	2200 4270	1.04 1.03	92 8	1.93 - 1.95
HOOC-PIB ₁₀₀₀ -COOH	Eq. #7	1230 2320	1.07 1.04	90 10	1.93 - 1.95

(e) OCN-PIB-NCO

The target isocyanate ditelechelic polyisobutylene employed in synthesis by Equation #2, was prepared by reaction HO-PIB-OH with excess MDI (equation #8).



- 5 Table 4 shows the reagent stoichiometries employed. After removing the solvent, the products were used in polycondensations without further purification. Depending on the HO-PIB-OH/MDI ratio, the products contained different amounts of chain extended PIB and unreacted MDI. Table 3 provides this information, generated by GPC (RI) eluograms. In the course of the polycondensation the
- 10 excess MDI is consumed and gives the hard PA phase.

A typical synthesis was carried out as follows: Under a blanket of nitrogen in a four neck flask equipped with a magnetic stirrer, pressure equalized dropping funnel, thermometer and a reflux condenser, a solution of the diisocyanate in THF (dried over CaH_2) was added to a solution of the HO-PIB-OH in dry THF. Table

15 4 shows the HO-PIB-OH/MDI ratio used. The mixture was refluxed for 2.5 hours and after removing the THF by vacuum, diisocyanate telechelic prepolymer was obtained.

Table 3

Composition of isocyanate ditelechelic polyisobutylenes
(Characterization by GPC; % values calculated from RI - signal area)

Products	unreacted MDI	OCN-PIB- NCO	once chain extended	twice chain extended	three times chain extended
Eq. #8	m	n=1	n=2	n=3	n=4
OCN-PIB ₁₀₀₀ -NCO(1)	2.4	20.1	27.4	50.1	
OCN-PIB ₁₀₀₀ -NCO(2)	4.1	21.7	21.7	16.5	36
OCN-PIB ₁₀₀₀ -NCO(3)	48.3	48	3.7		
OCN-PIB ₁₀₀₀ -NCO(4)	47.3	47.8	5.9		
OCN-PIB ₁₀₀₀ -NCO(5)	43.7	56.3			

Polycondensation

*Synthesis of polyamides (PA), and (PTHF-PA)_n and (PIB-PA)_n multiblocks by
Equation #1*

The synthesis of polyamides, (PTHF-PA)_n and (PIB-PA)_n, according to equation #1 were carried out using a solution polycondensation reaction. The syntheses of the PA- and the PTHF- based multiblocks were carried out in tetramethylenesulfone (TMS). Because of the simultaneous use of polar and nonpolar reactants in the (PIB-PA)_n synthesis, polar/nonpolar solvent mixtures, such as TMS/xylene were employed. Polycondensation conditions are described in Table 4.

A typical polycondensation was carried out under a blanket of nitrogen in a four neck flask equipped with a magnetic stirrer, pressure equalized dropping funnel and thermometer. Solvents were dried over CaH₂ and distilled under a blanket of N₂. The carboxyl ditelechelic PIB, the low molecular weight

dicarboxylic acids, and about 20 mg NaOCH₃ were dissolved in xylene/TMS (60:40 up to 75:25 vol.%) under stirring and heating. At the preselected temperature, a solution of diisocyanate in xylene/TMS (50:50 up to 0:100 vol.%) was added dropwise (70% of the diisocyanate during the first two hours, 80% after three hours, and then slowly dropwise until completion). The reaction was accompanied by gas evolution. After the reaction was completed, the charge was precipitated into acetone. After 12 hours the precipitate was filtered, washed for 24 hours in methanol under stirring, filtered and vacuum dried for five days at 60°C.

10 *Synthesis of (PIB-PA)_n by Equation #2*

The polycondensation was carried out under a blanket of nitrogen in the same reaction vessel used for the synthesis of OCN-PIB-NCO prepolymer. After addition of the low molecular weight dicarboxylic acids (NCO:COOH = 1:1.08), ~20 mg NaOCH₃ were added, xylene/TMS (65:35 vol.%), and the charge was quickly heated to the polycondensation temperature. Gas evolution and an increase in viscosity occurred during the heating. Stirring for 4 more hours resulted in a decrease in the viscosity. Subsequently, a solution of MDI in TMS was added over a period of one hour until the desired COOH:NCO was achieved. The product was recovered as described above for the products by Equation #1.

20 *Results and Discussion*

The objective of this research was the preparation of novel (PIB-PA)_n multiblock thermoplastic elastomers consisting of thermally stable rubbery polyisobutylene blocks connected to thermally stable crystalline polyamide blocks having melting points in the 220 - 280°C range. This combination of soft and hard moieties yielded good physical-mechanical properties and also melt processability. Thermoplastic elastomers were made by solution polycondensation of HOOC- or OCN- ditelechelic PIB's according to Equation #1 or #2.

Synthesis of Polyamides

To control the melting point of the polyamide moieties, orienting experiments were carried out with various diisocyanates plus different dicarboxylic acid (adipic/azelaic acid) mixtures. The mixtures of adipic and azelaic acids were chosen because the melting point of polyamides made with different proportions of these acids can be readily controlled over the desirable 240 - 320°C range. Data in Table 4 shows reaction conditions and corresponding results (Table 5) for the preparation of various polyamides (PA1 to PA5). Assuming that the polymer composition is equivalent to the feed composition (and that all amide groups have been trifluoroacetylated), the value m (see Equation #1) and the average number of amide bonds per chain ($2m$) can be readily calculated from the molecular weights of the polycondensation products and the starting materials. Column 6 in Table 5 shows the estimated average number of amide bonds per chain (22 - 97) in the polyamides obtained.

The two melting points of PA1 may be due to crystallites containing unequal proportions of adipic/azelaic acids. This PA exhibited outstanding thermal resistance (5% decomposition at 352°C). PA2 prepared with CHDA plus MDI melted at 249°C, was only sparingly soluble in TMS, and exhibited a barely acceptable decomposition temperature (274°C) for melt processing. The solubility characteristics of PA3 and PA4 prepared with "non-linear" diisocyanates (HMDI, XDI) were good, however, their melting points were less than desirable and exhibited poor crystallization behavior (i.e., after the first melting repeated heating/cooling cycles by DSC gave irreproducible melting point readings). PA5 obtained with adipic acid plus HDI formed in excellent yield, was of high molecular weight, exhibited acceptable melting point, and showed excellent thermal resistance. The repeat structures of PA5 and nylon-6,6 are, necessarily identical, however our PA exhibits $mp = 232^{\circ}C$ (in contrast to commercial nylon-6,6 with $mp = 265^{\circ}C$) most likely because of the molecular weight of the former is lower than the conventional material. According to these experiments

PA1 and PA5, because of their relatively high melting points and excellent thermal resistance, appear suitable to provide the hard phases in (PIB-PA)_n multiblock copolymers.

Multiblock Syntheses by Equation #1

5 (PIB-PA)_n were synthesized by reacting HOOC-PIB-COOH plus dicarboxylic acids with stoichiometric amounts of diisocyanates (small excess). Since the prepolymers were prepared by Equation #5 or #6, the hard/soft phase boundary in these (PIB-PA)_n's is predominantly formed by ester groups.

10 The second group of data in Table 4 show respective experimental conditions for the synthesis of HOOC-PTHF-COOH and results (Table 5). High yields of pale yellow high molecular weight products were obtained with melting points at 194 and 226°C. The products were thermally quite stable in nitrogen, however, in air at ~150°C, they started to gain weight (~1.5 %) indicating the onset of oxidation. At ~280°C, significant decomposition accompanied by heat
15 evolution and weight loss (burning) occurred. According to these observations, the oxidative resistance of PTHF-based TPE's are less than satisfactory than that achieved using PIB-based TPE's.

The third group of data in Table 4 show the conditions and results of experiments carried out with HOOC-PIB-COOH. Reasonable to high yields (69 -
20 94%), high molecular weights, and desirably high melting points (from 223 to 284°C) products were obtained. The two melting points exhibited by PIB₂₀₀₀-PA1(1) are most likely due to crystallites with different adipic/azelaic acid ratio. The same phenomenon has been observed with PA1. Figure 1 shows representative GPC traces obtained in the course of the synthesis of PIB₁₀₀₀-PA2(1)
25 (see Table 4). The molecular weight of the HOOC-PIB₁₀₀₀-COOH prepolymer (see Table 2) is shifted to somewhat higher values (lower elution counts) relative to the HO-PIB₁₀₀₀-OH starting material on account of the two additional adipic acid units. The small peak of the HOOC-PIB₁₀₀₀-COOH trace indicates the presence of ~10 % chain extended material. The large broad peak of the PIB₁₀₀₀-PA2 (1) shifted to

higher molecular weights relative to the prepolymers and the two small peaks in the 41 - 42 elution count range suggest a contribution by lower molecular weight components.

The samples were also characterized by light scattering (LS). Polymers with $M_n \geq 15000$ g/mol gave good signals and the molecular weight data obtained by LS and GPC were in reasonable agreement.

The values for n and m in Equation #1 (n = average number of PIB segments per chain; m = average number of hard segment repeating units which can be controlled by the HOOC-PIB-COOH/HOOC-R'-COOH ratio) can be calculated by assuming that the charge and product compositions are equal (or equivalent at less than complete conversions). From n and m , the average number of amide bonds formed per chain; $n(2m + 2)$, can be calculated. Columns 4 - 6 in Table 5 show the data according to which the number of amide bonds in (PIB-PA) $_n$'s prepared by Equation #1 were in the 23 - 41 range.

PIB₂₀₀₀-PA2(1) was crosslinked because of the relatively large quantity of diisocyanate employed (the sum of -COOH/NCO ratio was 3.92:4.61 (or 1: 1.17) (see Table 4). Crosslinking was due to the formation of acyl urea groups -N(-CO-NH-)-CO- which, however, could be dissolved by stirring the product for 48 hours at 80°C in a mixture of xylene / dimethylformamide (DMF) / di-N-butylamine (54 / 43 / 3 vol.%). The final product (bimodal by GPC) contained ~7% crosslinked material. The products swelled in THF, CH₂Cl₂, HCCl₃, and xylene at room temperature, however, dissolved (27 g/L) in 90/10 THF/DMF mixtures leaving 2 - 5% gel. The gels could be solubilized after N-trifluoroacetylation which suggests that this fraction consisted mainly of polyamides and/or products with high polyamide contents.

The T_g 's of the PIB₂₀₀₀-PA and PIB₁₀₀₀-PA multiblocks were -49°C and -18°C, respectively, which is much higher than that of the HO-PIB-OH starting materials. This T_g elevation occurs because of the relatively low molecular weights (M_n = 1950 and 975 g/mol) of the soft segments (decreasing free volume

in the multiblocks). The T_g of a PIB-based polyurethane made with HO-PIB-OH of $M_n = 1800$ g/mol also exhibited $T_g = -49^\circ\text{C}$. The T_g of the soft phase could be decreased by increasing the length of the polyisobutylene chain or by using polyisobutylene prepolymers containing no aromatic initiator fragments.

- 5 Importantly, all the PIB-PA(1)'s exhibited satisfactorily high melting points and high decomposition temperatures (excellent thermal stability) both in N_2 and air (see Table 4). This is contrast to PTHF-based thermoplastic elastomers which showed noticeably lower decomposition temperatures in air. Limited stress/strain data with PIB₁₀₀₀-PA2 (1) was obtained. Dumbbells punched from compression
10 molded transparent slightly yellow sheets gave the following data (averages of 3 determinations) 17 MPa tensile strength and 84% elongation at 508 mm/min, and 14 MPa with 102% elongation at 50.8 mm/min. The low elongation, due to the relatively short effective polyisobutylene segments could be enhanced by the use of higher molecular weight polyisobutylenes.

15 ***Multiblock Syntheses by Equation #2***

- Multiblock copolymers were obtained by the condensation of diisocyanate telechelic prepolymers with low molecular dicarboxylic acids. The prepolymers were OCN-PIB-NCO (partly chain extended) contained some unreacted MDI (see Table 3). Since the prepolymers are formed by the reaction of HO-PIB-OH with
20 MDI (eq 8), the multiblock copolymers contain urethane bonds at the hard/soft phase boundary. Prepolymer synthesis and the polycondensation were carried out in one-pot. As the reaction mixture was heated to 150°C , crosslinking by allophanate groups $-\text{N}(\text{CO-NH-})\text{CO-O-}$ caused the viscosity to increase significantly, which impeded stirring and reduced the yield. Since the allophanate
25 bond is thermally unstable and starts to release isocyanate groups above 150°C , the viscosity of the charge decreased upon further heating.

As shown by the first two lines of the fourth group of data, the HO-PIB-OH : MDI ratio for the synthesis of the prepolymers OCN-PIB₁₀₀₀-NCO was 1 : 1.92 or 1.79 (see Table 4). Strongly chain extended prepolymers

containing only a small amount of free MDI (see Table 3) were obtained and only a small amount of polyamide hard phase was formed during the polycondensation. According to DSC, PIB₁₀₀₀-PA1(2) and PIB₁₀₀₀-PA2 (2) exhibited only one T_g at -4 and -8°C, respectively. They are not phase separated.

5 By increasing the HO-PIB-OH : MDI ratio to 1 : 4.21 - 5.31 (see lines 3 - 5 of this group of data in Table 4), low M_n prepolymers which contained 40 to 50% unreacted MDI were obtained (see Table 3). Hard phase formation was sufficient for good phase separation and the multiblocks exhibited a T_g in the -21 to -28°C range, (quite similar to the low T_g's obtained with products prepared by
10 Equation #1) and depending on the adipic/azelaic acid ratio used, a polyamide melting point in the 230 to 279°C range. The thermostability of the products was adequate albeit somewhat lower (because of the urethane groups) than those prepared by Equation #1.

Novel (AB)_n-multiblock thermoplastic elastomers consisting of
15 polyisobutylene soft phases and polyamide hard phases were synthesized as outlined by Equations #1 and #2. Syntheses by Equation #1 led to high yields and gave high melting polyamide phases. By varying the structure of the polyamide it was possible to adjust the melting points of the hard phase in the range of 223 - 284°C. The polymers are thermostable in N₂ and in air up to 296 - 337°C, and
20 they are melt processable. Compression molding yielded pale yellow transparent and tough sheets. It is anticipated that the use of higher molecular weight polyisobutylene prepolymer would decrease the T_g of the soft phase and would improve the mechanical properties, particularly that of elongation.

The synthesis of the diisocyanate telechelic prepolymers (Equation #8) and
25 the subsequent polycondensation according Equation #2 were carried out in one-pot. The products were thermostable up to 267 - 298°C under nitrogen. Because the polycondensation according Equation #2 is complicated by temporary allophanate crosslinking, Equation #1 appears to be the better alternative at this time, for the preparation of (PIB-PA)_n thermoplastic elastomers.

Table 4
Reaction Conditions & Yield

Product	Di-carboxylic acid	Di-isocyanate	Ptc polymer	Feed Composition (molar equivalents)		hard phase (wt-%)	Time (hrs)	Temp (°C)	Yield (%)
Homopolyamides									
PA1	Adipic/ Azelaic*	MDI	0	1	1.07	100	5.5	170	77
PA2	CHDA	MDI	0	1	1.08	100	3	170	72
PA3	Adipic/ Azelaic	EXDI	0	1	1.08	100	5	170	28
PA4	Adipic/ Azelaic	XDI	0	1	1.08	100	5	170	82
PA5	Adipic	HDI	0	1	1.08	100	5	170	98
Multiblock copolymers from HOOC-PTHF-COOH									
PTHF ₁₀₀₀ -PA1(1)*	Adipic/ Azelaic	MDI	1	0.3	1.4	40	5.5	170	84
PTHF ₁₀₀₀ -PA2(1)	Adipic/ Azelaic	MDI	1	2.04	3.28	58	5.5	170	96

Product	Di-carboxylic acid	Di-isocyanate	Feed Composition (molar equivalents)			hard phase charged (wt %)	Time (hrs)	Temp (°C)	Yield (%)
			Pre-polymer	Di-carboxylic acid	Di-isocyanate				
<i>Multiblock copolymers from HOOC-PIB-COOH</i>									
PIB ₂₀₀₀ -PA1(1)	Adipic/Azelaic	MDI	1	3.13	4.48	35	8.5	160	75
PIB ₂₀₀₀ -PA2(1)	Adipic	HDI	1	2.92	4.61	24	5.5	150	94
PIB ₁₀₀₀ -PA1(1)	Adipic/Azelaic	MDI	1	1.27	2.45	43	8	150	69
PIB ₁₀₀₀ -PA2(1)	Adipic/Azelaic	MDI	1	1	2.16	40	8	150	91

Product	Di-carboxylic acid	Di-isocyanate	Feed Composition (molar equivalents)			hard phase charged (wt %)	Time (hrs)	Temp (°C)	Yield (%)
			Di-carboxylic acid	Di-isocyanate	Pre-polymer				
Multiblock copolymers from OCN-PIB-NCO - HO-PIB-OH:									
PIB ₁₀₀₀ -PA1(2)	Adipic/Azelaic	MDI	1	0.92	1.92	24	5.5	144	36
PIB ₁₀₀₀ -PA2(2)	CHDA	MDI	1	0.79	1.79	21	5.5	144	40
PIB ₁₀₀₀ -PA3(2)	Adipic/Azelaic	MDI	1	4.08	5.31	70	5.5	150	34
PIB ₁₀₀₀ -PA4(2)	Adipic/Azelaic	MDI	1	4.01	5.21	62	5.5	150	30
PIB ₁₀₀₀ -PA5(2)	Adipic/Azelaic	MDI	1	3.01	4.21	57	5.5	150	46

- (a) parenthetical (1) and (2) indicate the equation # synthesis route
- (b) the subscripts show the M_n of the prepolymers
- (c) adipic/azelaic acid ratio was 30/70 mol % (except in PIB₁₀₀₀-PA1(1) and PIB₁₀₀₀-PA4(2) (40/60 mol %))
- (d) poor crystallization behavior
- (e) exact melting point not determined because of broad melting peaks and/or small enthalpy of melting
- (f) soft phase content calculated from PIB or PTHF segments
- (g) prepolymer synthesis and polycondensation were carried out in the same flask without prepolymer workup - weighed amounts of prepolymers (molar equivalents are related to HO-PIB-OH)

Table 5
Product Characterization

Product	GPC		η_{inh}	n	Amide group per chain	DSC			Decomp temp N ₂ /air (°C)
	M_w (g/mol)	M_w/M_n	η_{inh} eq. (1) and (2)		$n(2m+2)$	Soft phase T_g (°C)	Hard T_g (°C)	Phase T_m (°C)	
Homopolyamides									
PA1	8000	1.4	15	—	30	—	103	232, 257	352/
PA2	5800	1.43	11	—	22	—	46	249	274/
PA3	7800	1.52	17	0	33	—	64	137 ^d	162/
PA4	9300	1.64	20	—	40	—	49	130 ^d	275/
PA5	20200	1.57	48	—	97	—	102	232	305/
Multiblock copolymers from HOOC-PTHF-COOH									
PTHF ₁₀₀₀ -PA1(1)	29300	1.68	0.3	17	45	-77	—	194 ^e	355/277
PTHF ₁₀₀₀ -PA2(1)	24800	1.75	2.04	9.5	58	-77	66	226	340/284

Product	GPC		m	n	Amide group per chain $2m$ or $n(2m+2)$	DSC			Decomp temp. N_2 /air (°C)
	M_w (g/mol)	M_w/M_n				in eq (1) and (2)	Soft phase T_g (°C)	Hard T_g (°C)	
Multiblock copolymers from HOOC-PIB-COOH									
PIB ₂₀₀₀ -PA1(1)	11800	1.37	3.13	2.8	23	-49	107	227, 255	324/320
PIB ₂₀₀₀ -PA2(1)	19200 (93%)	2.35	2.92	5.2	41	-49	108	240°	337/337
	115000 (7%)	2.37							
PIB ₁₀₀₀ -PA1(1)	12700	1.37	1.27	5.8	26	-18	—	284	310/296
PIB ₁₀₀₀ -PA2(1)	21400	1.7	1	10	40	-18	—	223	337/332

Product	GPC		n	m	in eq. (1) and (2)	Amide group per chain $2m$ or $n(2m+2)$	Soft phase T_g (°C)	DSC Hard T_g (°C)	Phase T_m (°C)	Decomp. temp. N ₂ /air (°C)
	M_w (g/mol)	M_w/M_n								
Multiblock copolymers from OCN-PIB-NCO - HO-PIB-OH										
PIB ₁₀₀₀ -PA1(2)	29200	2.07					-4	-	-	
PIB ₁₀₀₀ -PA2(2)	23500	1.61					-8	-	-	286/
PIB ₁₀₀₀ -PA3(2)	17500	2.12					-28	123	230	286/
PIB ₁₀₀₀ -PA4(2)	17800	2.13					-21	136	279	298/
PIB ₁₀₀₀ -PA5(2)	12800	1.81					-21	123	234°	267/

- (a) parenthetical (1) and (2) indicate the equation # synthesis route
- (b) the subscripts show the M_n of the prepolymers
- (c) adipic/azelaic acid ratio was 30/70 mol % (except in PIB₁₀₀₀-PA1(1) and PIB₁₀₀₀-PA4(2) (40/60 mol %))
- (d) poor crystallization behavior
- (e) exact melting point not determined because of broad melting peaks and/or small enthalpy of melting
- (f) soft phase content calculated from PIB or PTHF segments
- (g) prepolymer synthesis and polycondensation were carried out in the same flask without prepolymer workup - weighed amounts of prepolymers (molar equivalents are related to HO-PIB-OH

5

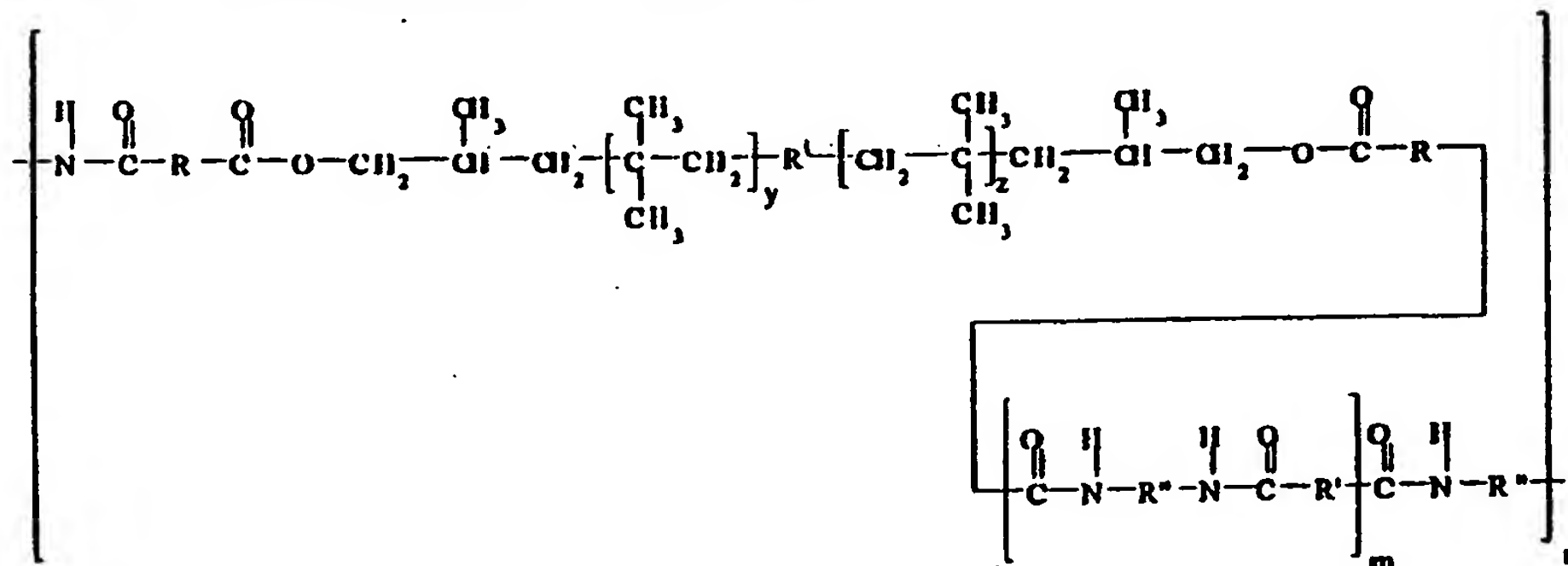
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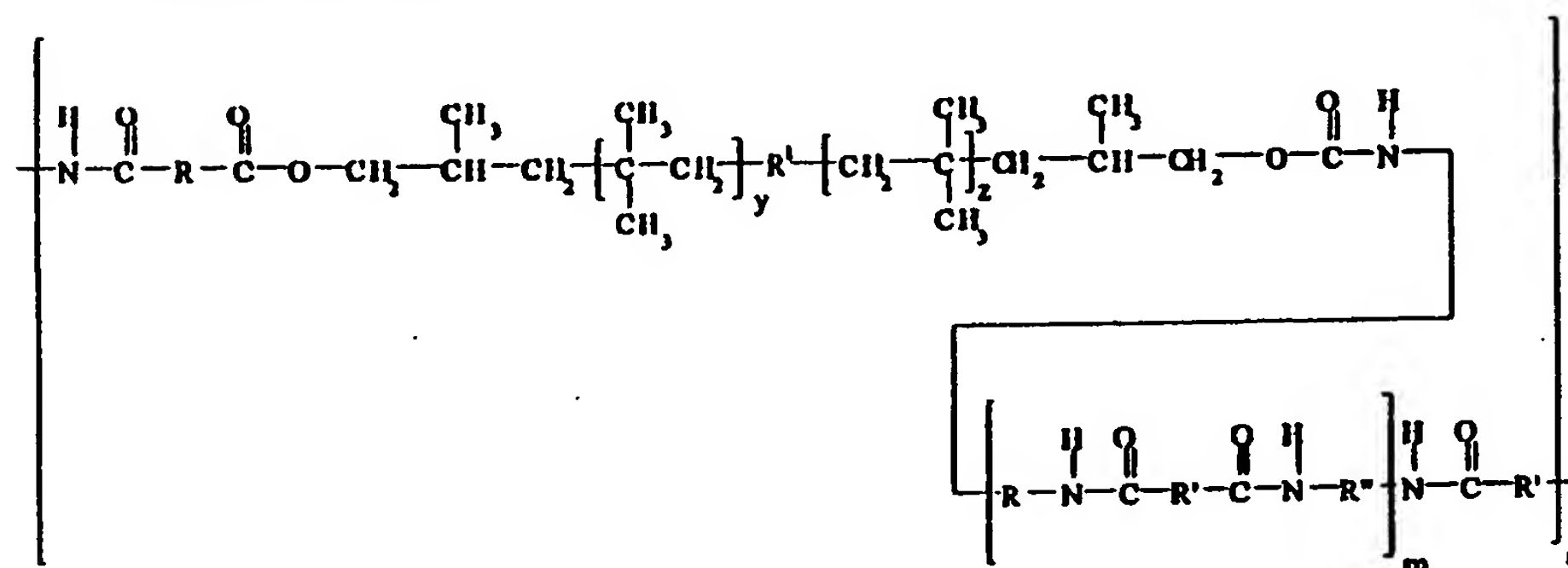
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Thus, in general what has been shown is a multiblock polymer product which comprises a polyisobutylene segment chemically bonded to a polyamide segment wherein the polyisobutylene segment and the polyamide segment form a repeating unit diblock copolymer wherein the diblock copolymer repeats at least two times

In a preferred embodiment, the polymer product will have a repeating unit is selected from the group consisting of formula (I)

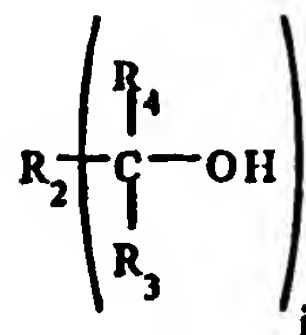


and formula (II)



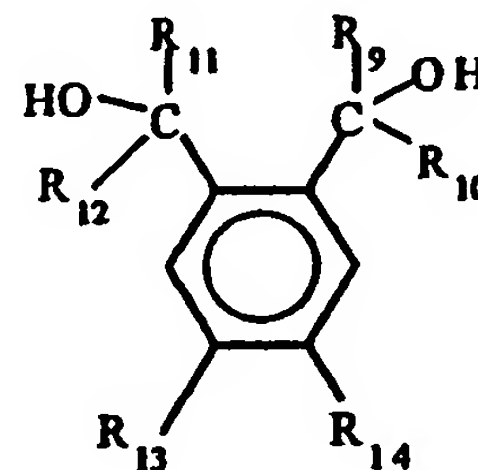
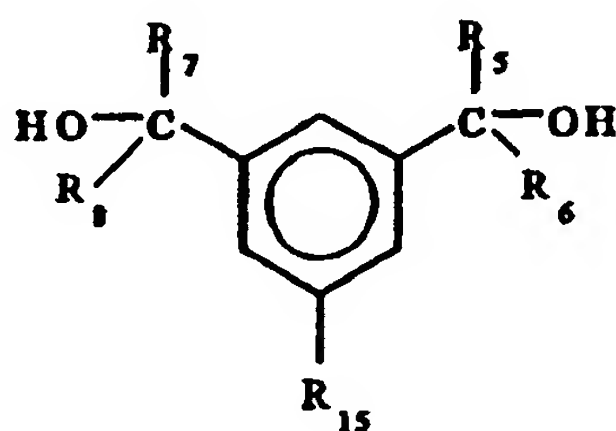
wherein R, R' and R'' are independently selected from the group consisting of C₂₋₂₀ aliphatic, cycloaliphatic, aromatic, aralkyl, alkaryl moieties and halogenated derivatives thereof; R' is an initiator of formula

26



wherein R_2 is selected from the group consisting of C_{1-24} alkyls, cycloaliphatic alkyls, aryls having from 1 to 4 phenyl rings, the rings being noncondensed or condensed, and halogenated derivatives thereof; R_3 is selected from the group consisting of hydrogen, methyl or phenyl; R_4 can independently be the same or different from R_3 ; and i is an integer which is at least 2; m is a number from 1 to 50; n is a number from 2 to 20; y and z are numbers from 9 to 100 and may be the same or different.

In a most preferred embodiment known at the time of this application, the product will have a substituent R_2 which is aryl or a substituted aryl

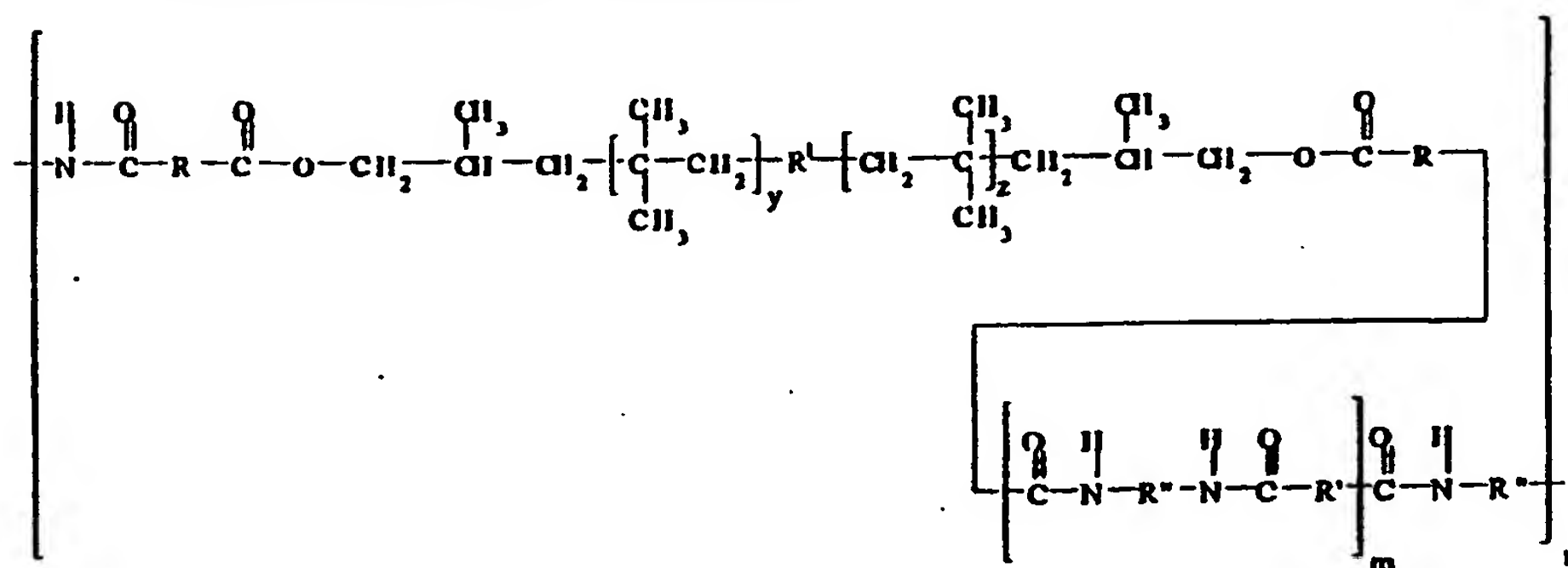


wherein R_{5-12} are independently hydrogen or alkyl groups having from C_{1-5} ; and R_{13-15} are independently hydrogen or alkyl groups having from C_{1-5} carbons or cycloalkyl groups having from C_{4-8} .

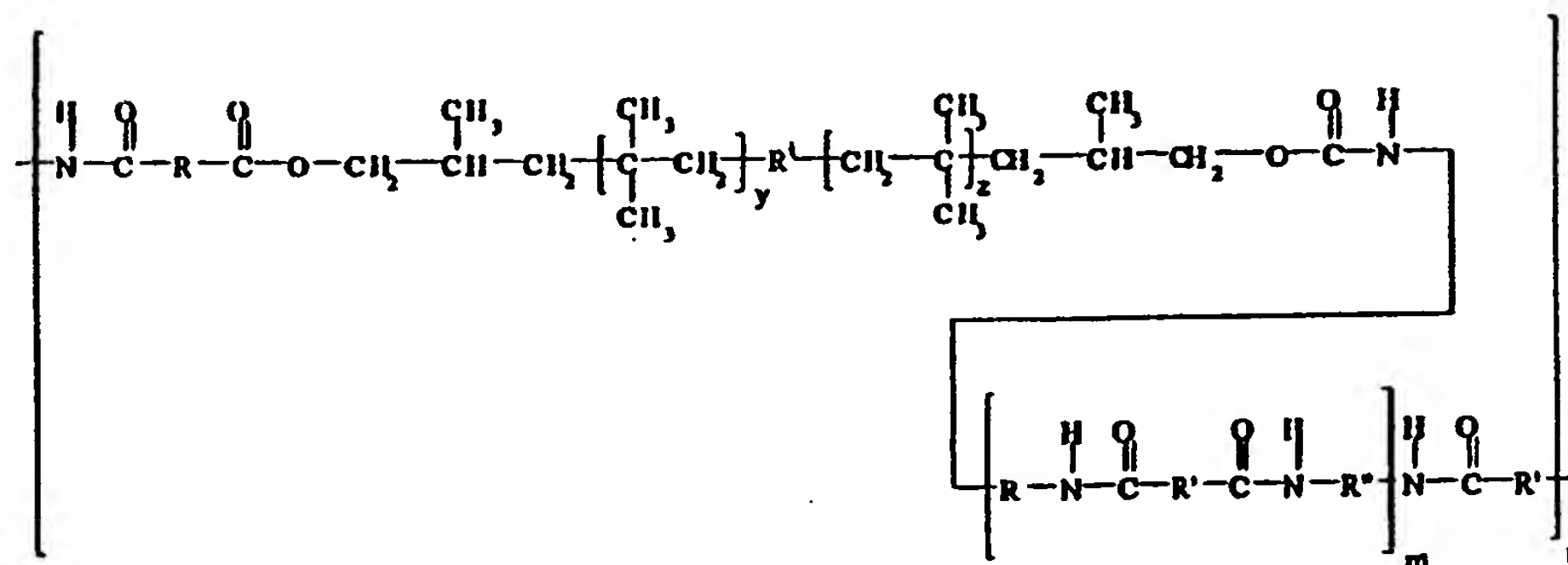
The invention has been described with reference to preferred and alternate embodiments. Obviously, modifications and alterations will occur to others upon the reading and understanding of the specification. It is intended to include all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

What is Claimed is:

1. A multiblock polymer product which comprises a polyisobutylene segment chemically bonded to a polyamide segment wherein the polyisobutylene segment and the polyamide segment form a repeating unit diblock copolymer wherein the diblock copolymer repeats at least two times.
2. The polymer product of claim 1 wherein the repeating unit is selected from the group consisting of formula (I)



and formula (II)

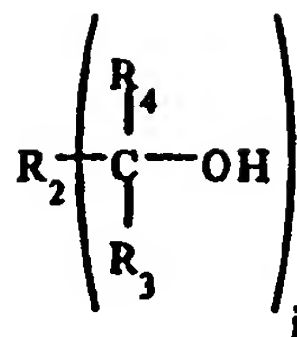


wherein

R, R' and R'' are independently selected from the group consisting of C₂₋₂₀ aliphatic, cycloaliphatic, aromatic, aralkyl, alkaryl moieties and halogenated derivatives thereof;

R' is an initiator of formula

28



wherein

R_2 is selected from the group consisting of C_{1-24} alkyls, cycloaliphatic alkyls, aryls having from 1 to 4 phenyl rings, the rings being noncondensed or condensed, and halogenated derivatives thereof;

R_3 is selected from the group consisting of hydrogen, methyl or phenyl;

R_4 can independently be the same or different from R_3 ; and

i is an integer which is at least 2;

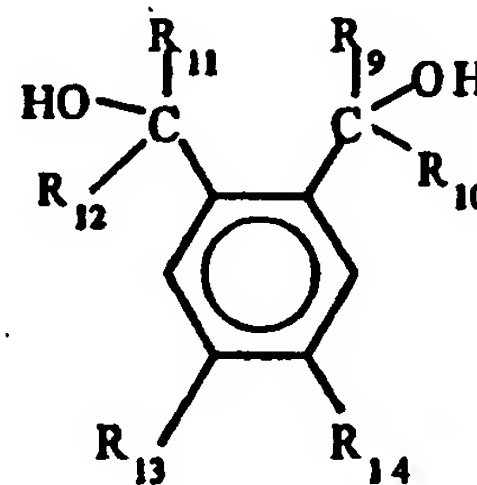
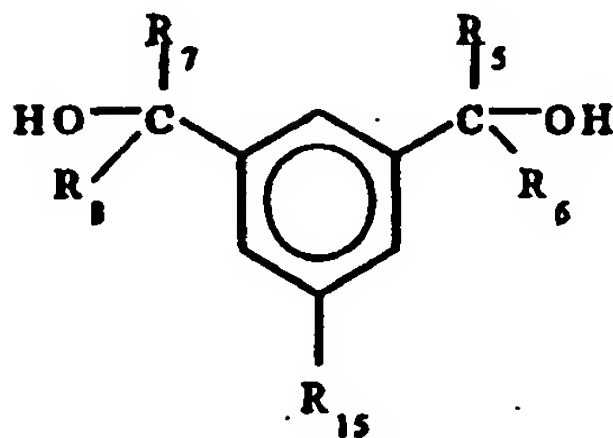
m is a number from 1 to 50;

n is a number from 2 to 20;

y is a number from 9 to 100; and

z is a number from 9 to 100.

3. The product of claim 2 wherein R_2 is aryl or a substituted aryl

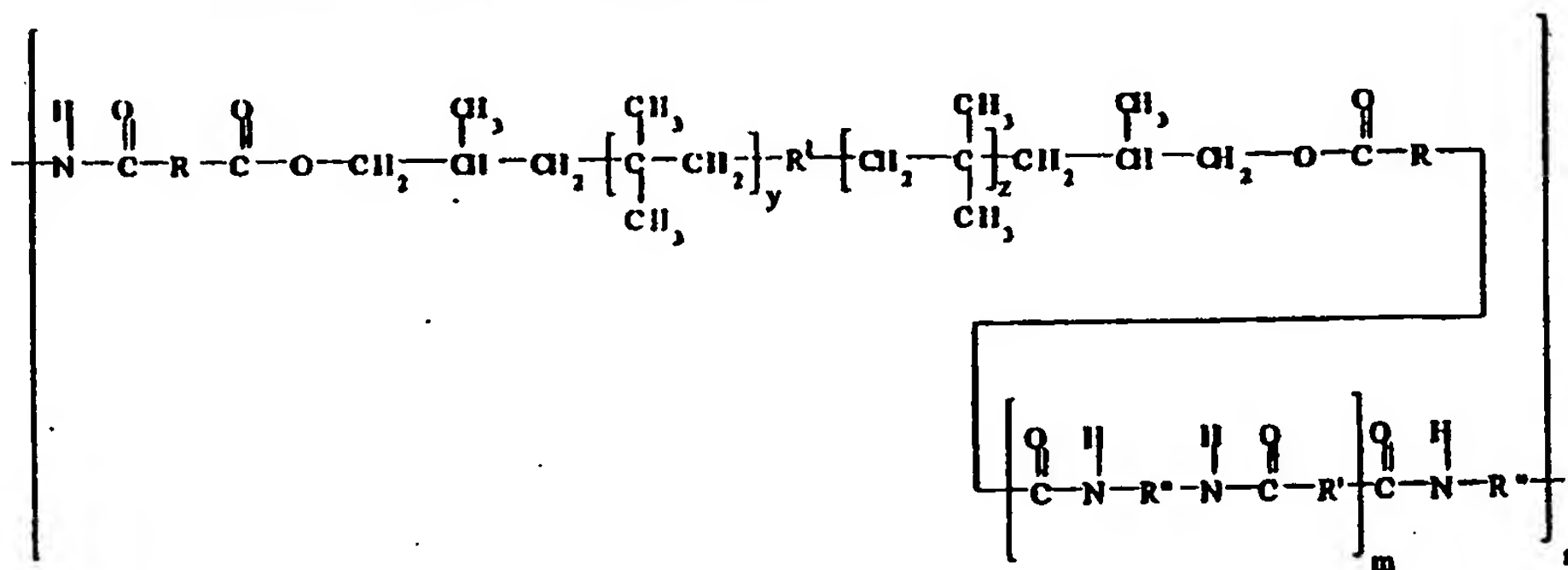


wherein

R_{5-12} are independently hydrogen or alkyl groups having from C_{1-5} ; and

R_{13-15} are independently hydrogen or alkyl groups having from C_{1-5} carbons or cycloalkyl groups having from C_{4-8} .

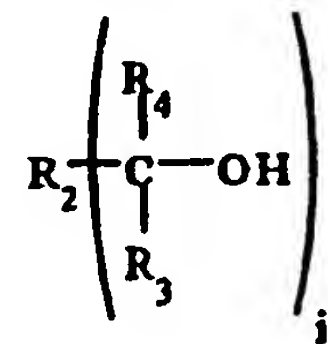
4. The polymer product of claim 2 wherein the repeating unit is selected from the group consisting of formula (I)



wherein

R , R' and R'' are independently selected from the group consisting of C_{2-20} aliphatic, cycloaliphatic, aromatic, aralkyl, alkaryl moieties and halogenated derivatives thereof;

R' is an initiator of formula



wherein

R_2 is selected from the group consisting of C_{1-24} alkyls, cycloaliphatic alkyls, aryls having from 1 to 4 phenyl rings, the rings being noncondensed or condensed, and halogenated derivatives thereof;

R_3 is selected from the group consisting of hydrogen, methyl or phenyl;

R_4 can independently be the same or different from R_3 ; and

i is an integer which is at least 2;

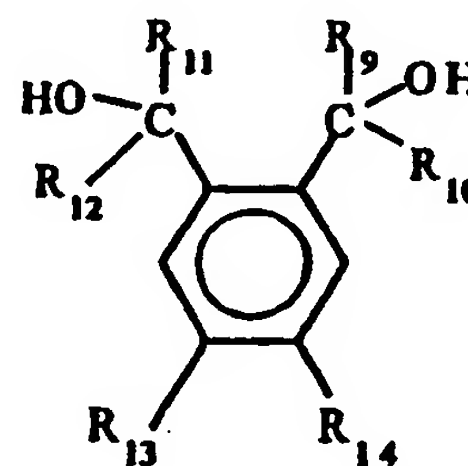
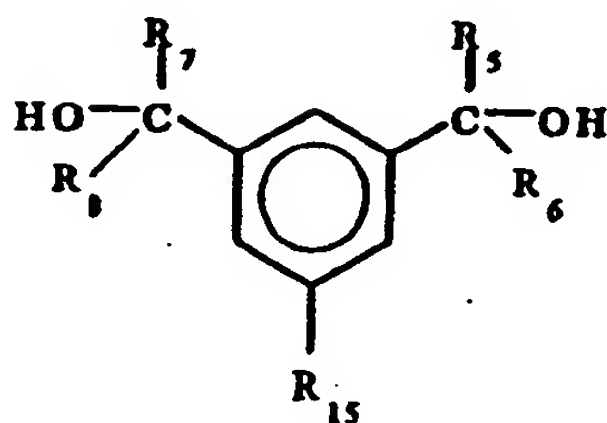
m is a number from 1 to 50;

n is a number from 2 to 20;

y is a number from 9 to 100; and

z is a number from 9 to 100.

5. The product of claim 4 wherein R_2 is aryl or a substituted aryl



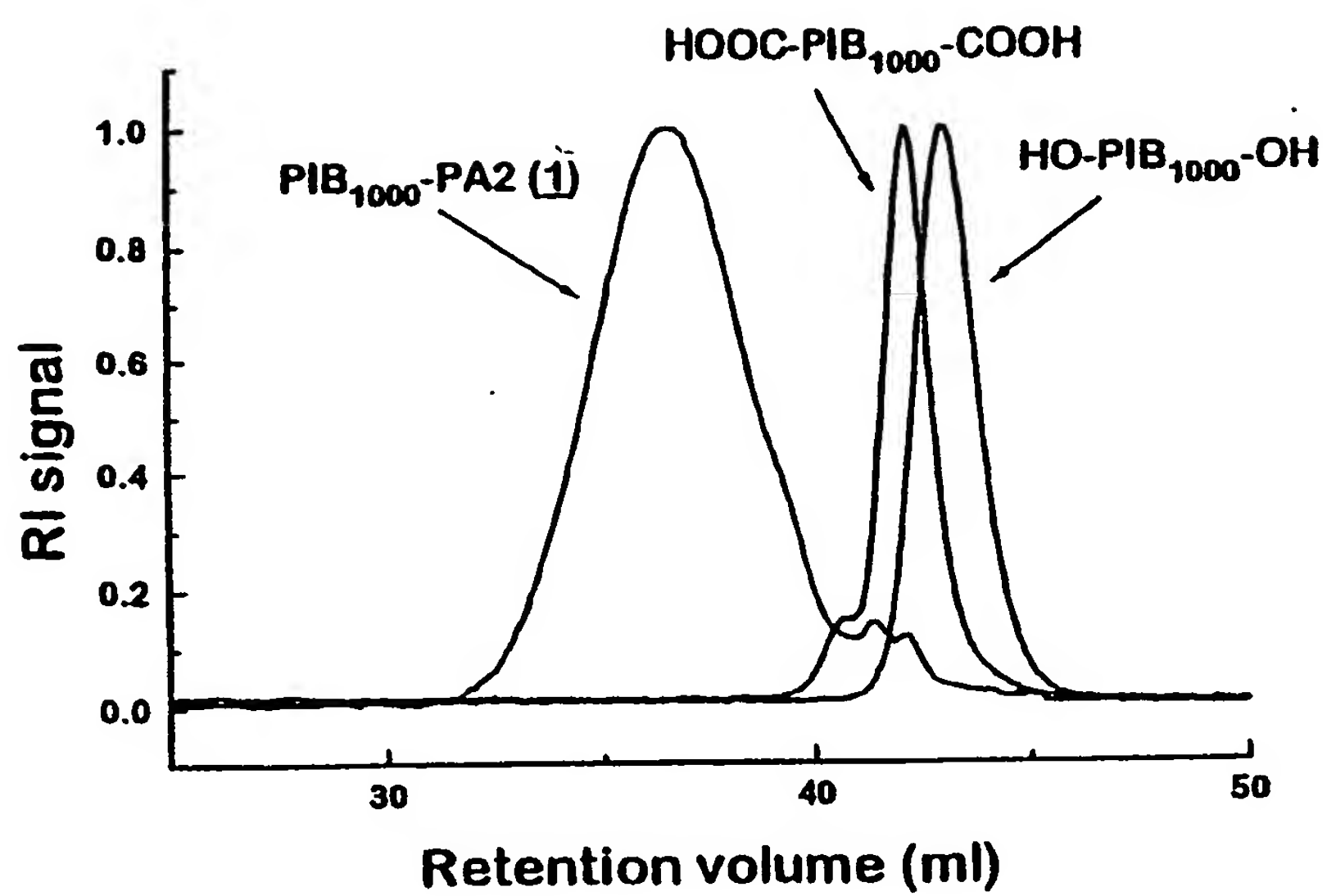
wherein

R_{5-12} are independently hydrogen or alkyl groups having from C_{1-5} ; and

R_{13-15} are independently hydrogen or alkyl groups having from C_{1-5} carbons or cycloalkyl groups having from C_{4-8} .

6. A process for the preparation for a multiblock polymer product which comprises a polyisobutylene segment chemically bonded to a polyamide segment wherein the polyisobutylene segment and the polyamide segment form a repeating unit diblock copolymer wherein the diblock copolymer repeats at least two times which comprises the steps of:
 - (a) cationically polymerizing isobutylene using an initiator having at least two functional end-groups which are hydroxide or capable of being converted into hydroxides to form a ditelechelic polyisobutylene;
 - (b) reacting the end-groups of the ditelechelic polyisobutylene with a dicarboxylic acid to form a carboxyl-terminated ditelechelic polyisobutylene prepolymer;
 - (c) reacting the prepolymer with at least one dicarboxylic acid and at least one diisocyanate; and
 - (d) recovering the diblock copolymer.
7. The process of claim 6 which wherein the step of reacting the prepolymer with at least one dicarboxylic acid and at least one diisocyanate occurs in a solvent.
8. The process of claim 7 wherein the solvent is a mixed solvent.
9. The process of claim 8 wherein the mixed solvent has at least one polar solvent and at least one non-polar solvent.
10. A process for the preparation for a multiblock thermoplastic elastomer which comprises a polyisobutylene rubbery segment chemically bonded to a polyamide hard segment wherein the rubbery segment and the hard segment form a repeating unit block copolymer wherein the unit repeats at least two times which comprises the steps of:
 - (a) cationically polymerizing isobutylene using an initiator having at least two functional end-groups which are hydroxide or capable of

- being converted into hydroxides to form a ditelechelic polyisobutylene;
- (b) reacting the end-groups of the ditelechelic polyisobutylene with a diisocyanate to form a diisocyanate-terminated ditelechelic polyisobutylene prepolymer;
 - (c) reacting the prepolymer with at least one dicarboxylic acid and at least one diisocyanate; and
 - (d) recovering the diblock copolymer.
11. The process of claim 10 wherein the step of reacting the prepolymer with at least one dicarboxylic acid and at least one diisocyanate occurs in a solvent.
 12. The process of claim 11 wherein the solvent is a mixed solvent.
 13. The process of claim 12 wherein the mixed solvent has at least one polar solvent and at least one non-polar solvent.

*Fig. 1*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/10162

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : CO8L 53/00, 77/00

US CL : 525/123, 183, 184, 419

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 525/123, 183, 184, 419

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, CAS ONLINE

ditelechellic, telechellic, polyisobutylene, isobutylene, polyamide, diisocyanate, polyisocyanate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,346,200 A (WOODBREY) 24 August 1982 (24.08.82), abstract.	1
X	US 4,845,158 A (PETERS) 04 July 1989 (04.07.89), Col. 11, lines 23-32.	1
X	WONDRACZEK et al. Nylon 6-Polyisobutylene Sequential Copolymers. II. Synthesis, Characterization, and Morphology of Di-, Tri-, and Radial Block Copolymers. Vol. 20, pages 173-190 (1982).	1

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	X	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	Y	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	&	document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means		
P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

26 AUGUST 1996

Date of mailing of the international search report

31 OCT 1996

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/10162

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WONDRACZEK et al. Synthesis and Characterization of Nylon-Polyisobutylene-Nylon Triblock Copolymers, I. Preliminary Studies. Vol. 2, pages 675-682 (1980).	

THE JOURNAL OF THE